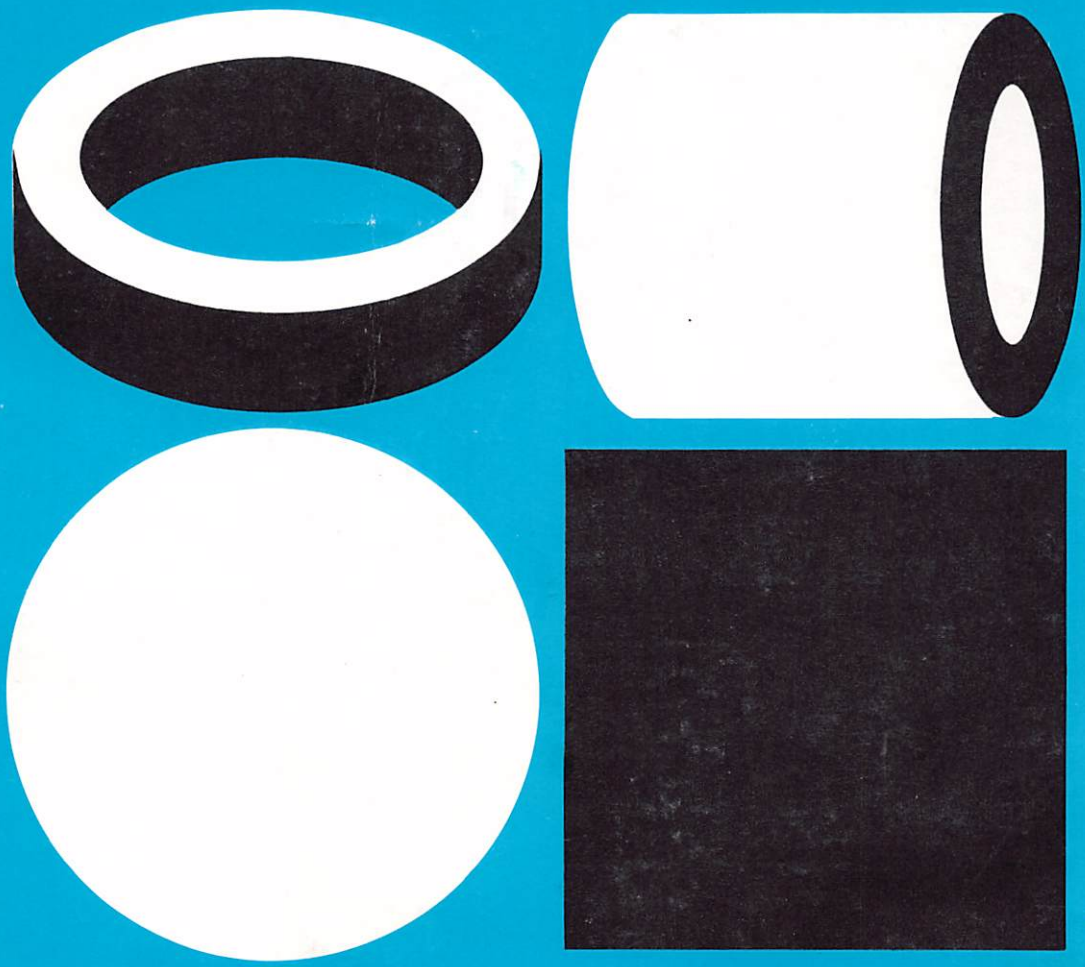
Modern Piezoelectric Ceramics

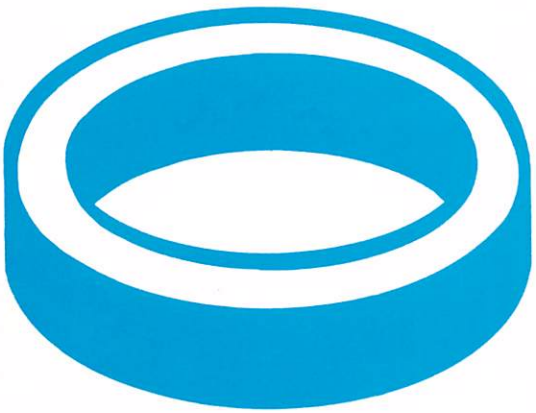
PIEZOELECTRIC DIVISION/CLEVITE

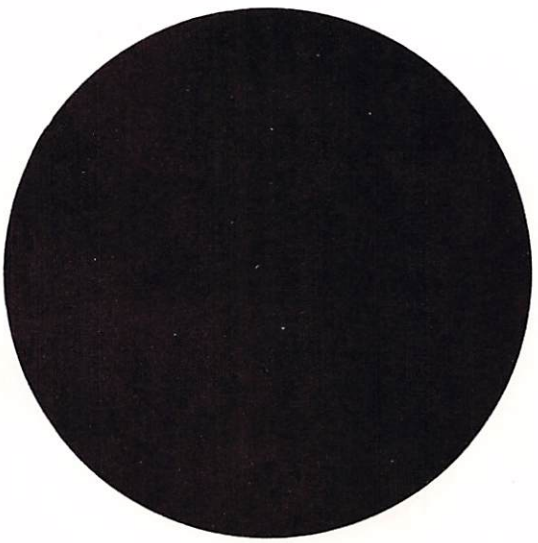


Modern Piezoelectric Ceramics

Clevite Electronic Components manufactures piezoelectric ceramics for electromechanical transducers used in sonar, ultrasonic and audio equipment. This catalog lists basic properties of Clevite standard piezoelectric ceramic materials, shapes and sizes. Many applications require custom designed shapes, sizes, tolerances, etc. The parts listed here are standard, "off-the-shelf" items recommended for experimental use, or for economical purchase in small quantity.

Clevite engineering services and publications are quite widely recognized in the field of piezoelectricity. Designers are encouraged to discuss present or potential application requirements with Clevite specialists without obligation. A partial list of Clevite technical reports on subjects of general interest in the field is abstracted on the opposite page. These reports are available upon request.





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Technical Information

A Primer on Piezoelectricity and Piezoelectric Ceramics *Bernard Jaffe*

A basic discussion of piezoelectricity and piezoelectric materials aimed at those persons with a limited knowledge of piezoelectricity. Both piezoelectric and ferroelectric action are outlined as well as the more common terms and constants involved in piezoelectricity.

Piezoelectricity—
Encyclopedia Britannica Hans Jaffe

Reprint of the section on piezoelectricity published in the latest Encyclopedia Britannica. Emphasis is placed on an easily understandable, yet comprehensive treatment of piezoelectricity. A brief history is given along with the description of the piezoelectric effect in various materials. The basic piezoelectric terms and constants are covered.

On The Meaning of "g" and "d" Constants as Applied to Simple Piezoelectric Modes of Vibration *C. P. Germano*

A basic treatment of perhaps the two most important constants associated with piezoelectricity. The role of these two constants in determining element displacement for a given applied electric charge, or conversely, developed charge for a given element displacement, is covered in such a manner as to be easily understood by those not overly familiar with piezoelectricity.

Piezoelectric High Voltage Generators
J. P. Arndt

A discussion of the high voltage generating capabilities of PZT® ceramics aimed at the engineer interested in the high voltage applications of these materials. The approach is not overly technical . . . emphasis being placed on the practical considerations involved in obtaining usable high voltage output from PZT ceramics.

Effects of High Static Stress on the Piezoelectric Properties of Transducer Materials
H. E. Krueger and Don Berlincourt
(JASA Vol. 33 No. 10, 1339-1344, Oct., 1961)

A study of effects of static compressive stress on the piezoelectric properties of PZT-4, PZT-5, Ceramic "B", and lead additive barium titanate. Comparisons of the permanent changes in piezoelectric characteristics of these materials after being subjected to varying amounts of maintained stress are made.

Power Limitations of Piezoelectric Ceramics in Radiating Transducers
Don Berlincourt

A theoretical treatment of the power handling capacity of various piezoelectric ceramics in sonar transducers. A review of the factors which limit power handling capacity of the various ceramics such as mechanical strength, dielectric losses, depolarization due to applied field, and temperature is included.

I. R. E. Standards of Piezoelectric Crystals: Measurement of Piezoelectric Ceramics *Vol. 49 No. 7, July, 1961*

Procedures for Measuring Properties of Piezoelectric Ceramics *J. P. Arndt*

Procedures are recommended for measuring piezoelectric ceramic material properties, based on the published IRE standards. Test specimen shapes and sizes are listed for measuring various properties, and suggested test circuits are shown, using common engineering laboratory equipment.

PZT-4—High Power Capacity

PZT-4—This material composition, unique even among the lead zirconates-lead titanates, is the best known piezoelectric ceramic for high power applications. In sonar projectors and ultrasonic cleaner transducers it provides up to 10 times more power conversion than other ceramic materials.

PZT-4 accepts more ac driving field (approx. 10 kv/cm, non-resonant) without depoling, has high electromechanical coupling and piezoelectric "d" constants (strain/applied field), and has the lowest dielectric dissipation factor of all Clevite ceramics. With a Curie point of 325°C and an unusually low tendency to self-heat, PZT-4 is strongly recommended for high level electrically driven transducers. In generator applications, it can be stressed more than any other piezoelectric ceramic without depoling—is now being used in new high voltage generator applications.

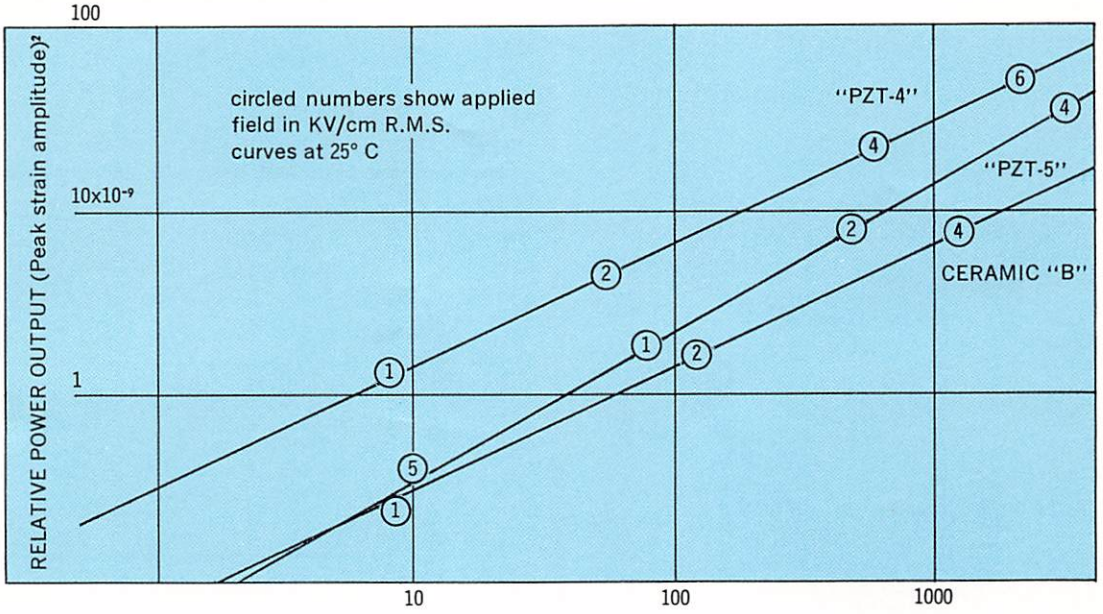
PZT-5—High Generating Sensitivity

PZT-5—This Clevite ceramic material has set a new standard for acoustic sensing transducers such as hydrophones. It offers the desirable combination of a high piezoelectric "g" constant (field/stress) and a high dielectric constant. This gives an underwater hydrophone high signal sensitivity and high internal capacity that reduces the effects of amplifier loading and cable capacity. PZT-5 has a Curie temperature of 365°C and unusually high resistivity even at high temperatures. Although its resistance to self-heating under high electric drive is not as good as PZT-4, it can be very efficient in a low power electrically driven transducer.

Ceramic "B"—Reliable, Economical

Ceramic "B"—Clevite's standard barium titanate ceramic composition is recommended for reliable transducer performance over its recommended range of operating power levels and temperature. Many standard sonar and hydrophone designs are based on barium titanate ceramic properties. When duplication of the original material is required, Ceramic "B" is recommended for this purpose.

Relative Power Output vs. Self Heating



One of the most serious limitations of high power transducers (e.g., sonar projectors) is the temperature rise due to internal losses. These curves show that for the same power lost in self-heating, PZT-4 delivers about seven times as much output power as Ceramic "B". Since PZT-4 can withstand much higher temperatures than Ceramic "B", its effective power handling capacity is even more favorable. Note, too, that the seven-fold advantage in output power is obtained with only slightly higher driving field.

Properties of Clevite Ceramics

Piezoelectric, Dielectric and Elastic Properties of Clevite Ceramic "B", PZT-4, and PZT-5 Ceramics. All values are nominal for design information only. Individual piezoelectric material constants can be measured with reasonable accuracy only when test specimens are of a size and shape suitable for each particular constant. It is recommended that material properties be measured according to standard IRE definitions and measuring techniques[1]. These material constants cannot be measured directly on most ceramic parts designed and purchased for use in particular transducers. To obtain part specifications that insure uniform quality, consult with Clevite for measurable characteristics that can be correlated to specific material constants.

[1] IRE Standards on Piezoelectric Crystals: Measurements of Piezoelectric Ceramics, 1961

DISCS

PLATES

TUBES

CUSTOM SHAPES

	Ceramic "B"	PZT®-4	PZT-5
Coupling Coefficients			
k_{33}	0.48	0.70	0.71
k_{31}	0.19	0.33	0.34
k_{15}	0.48	0.71	0.69
k_p	0.33	0.58	0.60
Piezoelectric Constants			
d_{33}	149×10^{-12}	285×10^{-12}	374×10^{-12}
d_{31}	-58×10^{-12}	-122×10^{-12}	-171×10^{-12}
d_{15}	242×10^{-12}	495×10^{-12}	584×10^{-12}
g_{33}	14.0×10^{-3}	24.9×10^{-3}	24.8×10^{-3}
g_{31}	-5.5×10^{-3}	-10.6×10^{-3}	-11.4×10^{-3}
g_{15}	21.0×10^{-3}	38.0×10^{-3}	38.2×10^{-3}
Free Dielectric Constants			
K_1	1300	1475	1730
K_3	1200	1300	1700
Frequency Constants			
N_1	2290	1650	1400
N_3	2740	2000	1770
N_4	1580	1310	1130
Elastic Constants— Short Circuit			
$1/s^E_{11} = Y^E_{11}$	11.6×10^{10}	8.2×10^{10}	6.1×10^{10}
$1/s^E_{33} = Y^E_{33}$	11.1×10^{10}	6.6×10^{10}	5.3×10^{10}
$1/s^E_{44} = Y^E_{44}$	4.4×10^{10}	2.6×10^{10}	2.1×10^{10}
Density	5,600	7,600	7,700
Mechanical Q	400	500	75
Curie Point	115°C	325°C	365°C

d = resulting strain/applied field in meters/volt

g = resulting field/applied stress in volt-meters/Newton

$N_1 = lf_r$, cps-meters, where l = length of a slim transverse expander bar

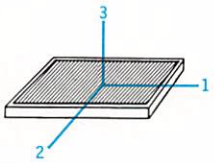
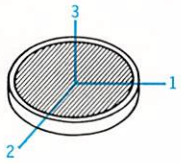
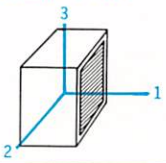
$N_3 = tf_r$, where t = thickness of a thin expander plate

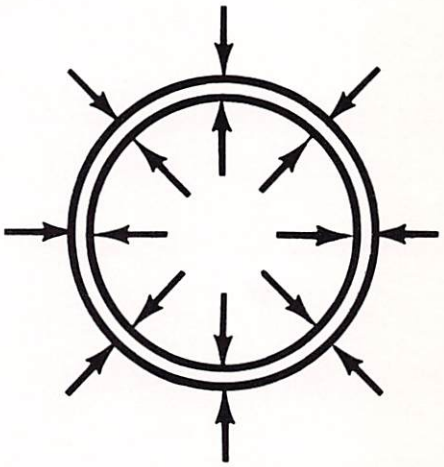
$N_4 = tf_a$, where t = thickness of a thin, thickness shear plate

1/s = Y in Newton/meter²

Density is kg/meter³

Piezoelectric Ceramics—basic actions

AXES	DESIRED ELECTROMECHANICAL EFFECTS	PIEZOELECTRIC, ELASTIC AND DIELECTRIC CONSTANTS
PLATES, BARS 	THICKNESS EXPANDER POLED FIELD STRAIN LENGTH EXPANDER POLED FIELD STRAIN	d_{33}, g_{33}, k_{33} Y_{33}, p K_3 d_{31}, g_{31}, k_{31} Y_{11}, p K_3
DISCS 	RADIAL EXPANDER POLED FIELD STRAIN THICKNESS EXPANDER POLED FIELD STRAIN	d_{31}, g_{31}, k_p Y_{11}, p K_3 d_{33}, g_{33}, k_{33} Y_{33}, p K_3
SHEAR PLATE 	SHEAR POLED FIELD STRAIN	d_{15}, g_{15}, k_{15} $Y_{44}=Y_{55}, p$ K_1
TUBES	THICKNESS EXPANDER LENGTH EXPANDER HOOP (Circumference Expander)	d_{33}, g_{33}, k_{33} Y_{33}, p k_3 d_{31}, g_{31}, k_{31} Y_{11}, p K_3



KEY TO SUBSCRIPTS. The subscripts 1, 2 and 3 indicate the x, y and z axes respectively. The subscripts 4, 5 and 6 represent a double subscript which in turn represents a plane; thus 4 represents the yz plane; 5 represents the xz plane; 6 represents the xy plane.

Piezoelectric Constants: The first subscript refers to the direction of the field; the second subscript refers to the direction of the strain.

Elastic Constants: The first subscript refers to the direction of the stress; the second subscript refers to the direction of the strain.

Dielectric Constants: This is a simplified notation referring only to the direction of the field.

Definitions:

d constant	strain/unit field	k_p	(planer coupling) electromechanical coupling coefficient, radial mode
g constant	open circuit field/unit stress	Y	Young's Modulus, ratio of stress to strain
k	electromechanical coupling coefficient	p	density
		K	Dielectric constant

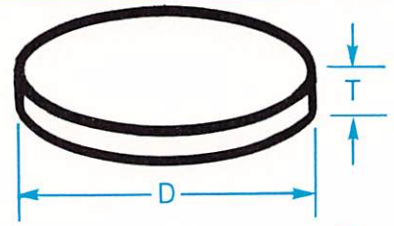
Standard Ceramic Parts

The following table lists some standard parts available from stock. Other standard and special parts are available.

When ordering please be sure to add the suffix denoting material as follows:

PZT-4—suffix-4
PZT-5—suffix-5
Ceramic "B"—suffix-B

For example: a 1" dia. x .270 thick. in PZT-4 would be designated as 16270-4. In Ceramic "B" the same size disc would be 16270-B.



DISCS

Part No.	D	T
4100	.250	.100
8100	.500	.100
8125	.500	.125
8250	.500	.250
12100	.750	.100
12125	.750	.125
12250	.750	.250
16100	1.00	.100
16125	1.00	.125
16270	1.00	.270
16500	1.00	.500
24100	1.50	.100
24250	1.50	.250
24270	1.50	.270
24375	1.50	.375
24500	1.50	.500
32250	2.00	.250
32500	2.00	.500
34250	2.125	.250
34500	2.125	.500
40500	2.50	.500

STANDARD TOLERANCES—DISCS

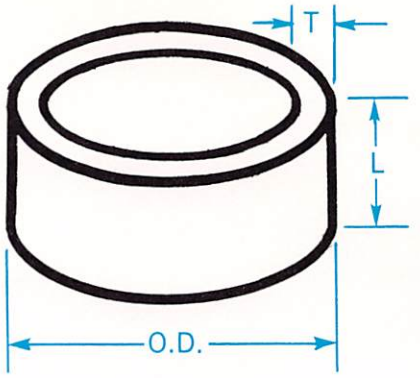
DIAMETER ± 0.015 in.

THICKNESS ± 0.005 in.

FLATNESS
Within .005 in. up to 1 in. O.D.
Within .010 in. from 1 in. to 2.5 in. O.D.

PARALLEL
Within .005 in.

SQUARENESS
Within 1 degree



TUBES

Part No.	L	O.D.	T
1-1010	.063	.063	.010
2-1010	.125	.063	.010
1-1015	.063	.063	.015
2-1015	.125	.063	.015
2-2015	.125	.125	.015
2-2020	.125	.125	.020
4-2020	.250	.125	.020
8-2020	.500	.125	.020
4-4020	.250	.250	.020
8-4020	.500	.250	.020
8-4063	.500	.250	.063
4-8031	.250	.500	.031
4-8125	.250	.500	.125
8-8031	.500	.500	.031
8-8125	.500	.500	.125
12-8125	.750	.500	.125
16-8125	1.000	.500	.125
8-16125	.500	1.000	.125
16-16125	1.000	1.000	.125
16-24125	1.000	1.500	.125
24-24125	1.500	1.500	.125
24-32200	1.500	2.000	.200
32-32200	2.000	2.000	.200
48-32200	3.000	2.000	.200
48-48200	3.000	3.000	.200
64-48250	4.000	3.000	.250

STANDARD TOLERANCES—TUBES

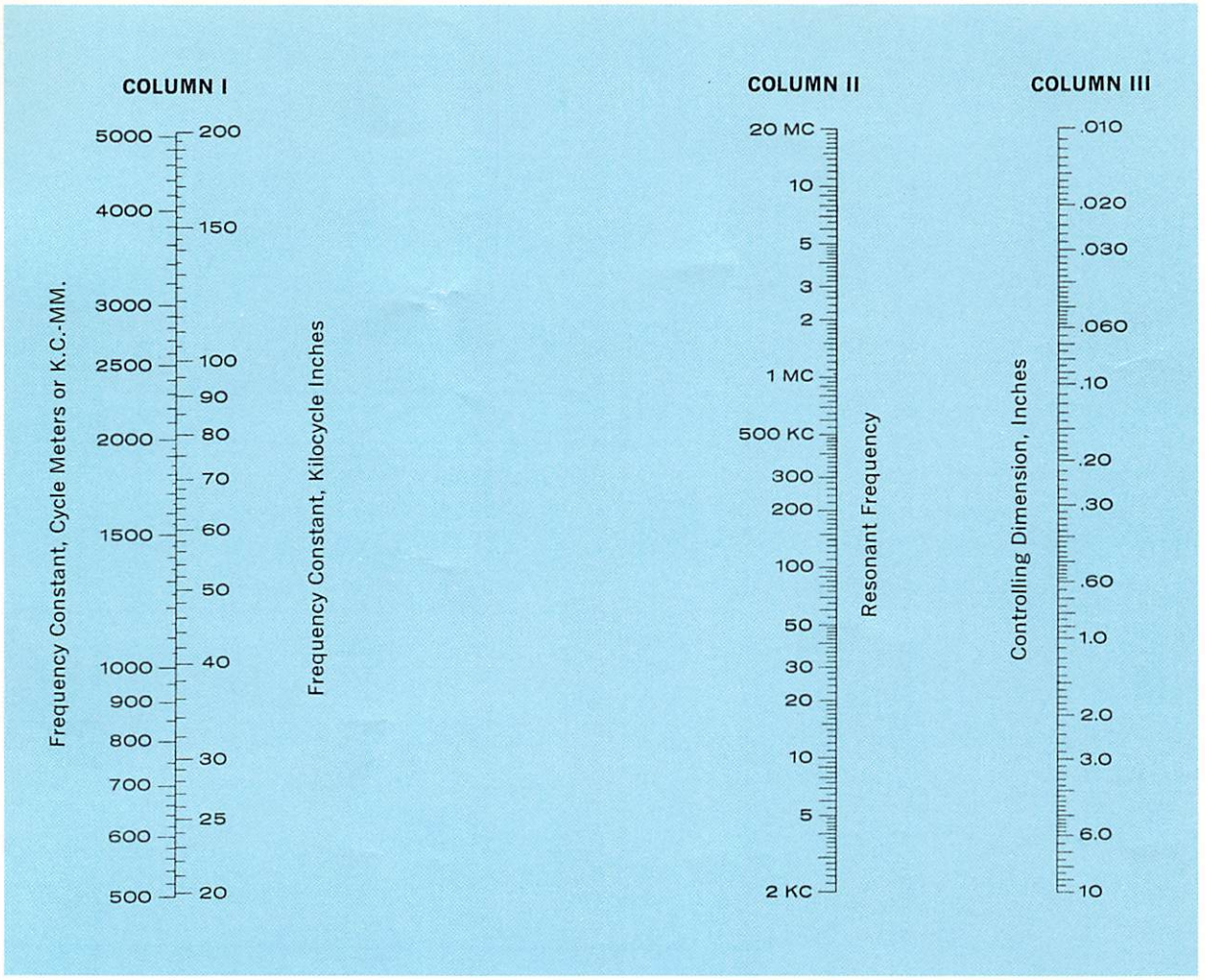
OD = up to 0.250" ± 0.015
OD = 0.250" up to 0.750' ± 0.020
OD = 0.750" up to 1.500' ± 0.030
OD = 1.500" up to 3.000" ± 0.050
OD = 3.000" up to 4.500" ± 0.090

T = 0.010" up to 0.025" ± 0.005
T = 0.025" up to 0.075" ± 0.010
T = 0.075" up to 0.250" ± 0.020
T = 0.250" and over ± 0.025

L = ± 0.015

OUT OF ROUND
Within the O.D. tolerances
1 degree per inch of length

Resonant Frequency



RESONANT FREQUENCY NOMOGRAPH

Determine the approximate resonant frequency of Clevite piezoelectric transducer elements by using the nomograph above and table of frequency constants below. Find the frequency constant of the desired Clevite ceramic from the table. With a straightedge, describe a line from that frequency constant in Column I of the nomograph to the controlling dimension, Column III, of the required mode. The line intersects Column II at the approximate resonant frequency. Determine the approximate controlling dimension for a given resonant frequency in the same manner.

FREQUENCY CONSTANTS (KC-IN)

Mode of Vibration		PZT-4	PZT-5	Ceramic "B"
Transverse	N_1	65	59	90
Thickness	N_3	78	71	110
Radial (Disc)*		90	82	120
Circumferential*		41	39	57

* Controlled by mean diameter

NOTE: Frequency constants listed apply only to shapes ideal for measuring material properties. For other shapes, the nomograph serves only as a guide to determining resonant frequency.

Ceramic Properties Definitions

PROPERTY	DEFINITION	MKS UNITS
Electro-Mechanical Coupling Coefficient k	$\sqrt{\frac{\text{mechanical energy stored}}{\text{electrical energy applied}}}$ $\sqrt{\frac{\text{electrical energy stored}}{\text{mechanical energy applied}}}$	
Piezoelectric Constants d	$\frac{\text{strain developed}}{\text{applied field}}$	$\frac{\text{meter/meter}}{\text{volts/meter}}$
	$\frac{\text{short circuit charge density}}{\text{applied stress}}$	$\frac{\text{coulombs/meter}^2}{\text{Newtons/meter}^2}$
g	$\frac{\text{open circuit field}}{\text{applied stress}}$	$\frac{\text{volts/meter}}{\text{Newtons/meter}^2}$
	$\frac{\text{strain developed}}{\text{applied charge density}}$	$\frac{\text{meter/meter}}{\text{coulombs/meter}^2}$
Relative Dielectric Constant K	$\frac{\varepsilon \text{ (permittivity of material)}}{\text{(permittivity of space)}}$	
Modulus of Elasticity Y	$\frac{\text{Stress}}{\text{Strain}}$	$\frac{\text{Newtons/meter}^2}{\text{meter/meter}}$
Density ρ		$\frac{\text{kg}}{\text{meters}^3}$ *
Frequency Constant N	Controlling Dimension x Resonant Frequency	cps-meters

*Multiply by 10^{-3} to get grams/cc (CGS)

Common MKS/English Conversions

Length

1 Meter = 39.37 inches
1 Inch = 2.54×10^{-2} meters

Area

1 Meter^2 = 1.55×10^{3} inches^2
1 Inch^2 = 6.452×10^{-4} meters^2

Volume

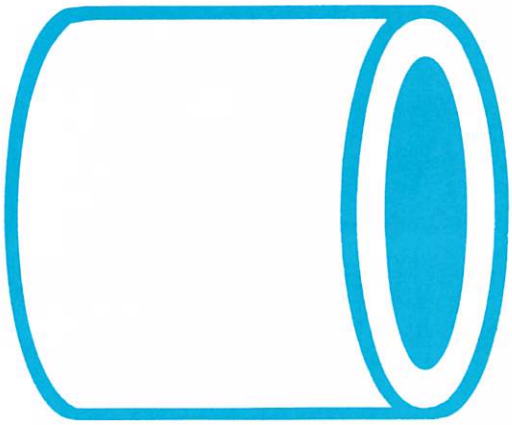
1 Meter^3 = 6.102×10^{4} inches^3
1 Inch^3 = 1.639×10^{-5} meters^3

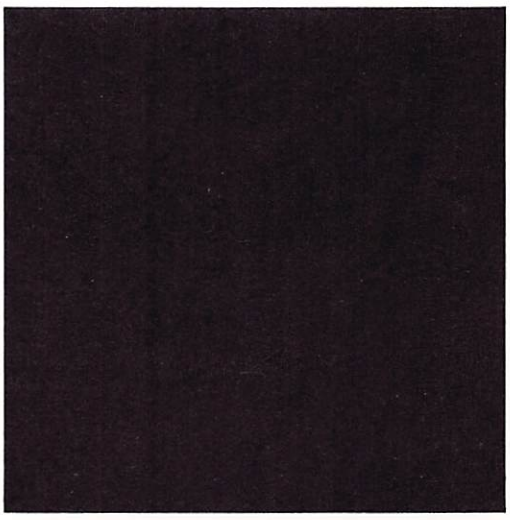
Force

1 Pound = 4.448 Newtons
1 Newton = 2.248×10^{-1} Pounds
1 Kilogram = 9.807 Newtons
1 Newton = 1.020×10^{-1} Kilograms
1 Pound = 4.536×10^{-1} Kilograms
1 Kilogram = 2.205 Pounds

Pressure

1 Pound/Inch^2 = 6.895×10^{3} Newtons/Meter^2
1 Newton/Meter^2 = 1.45×10^{-4} Pounds/Inch^2





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